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## **Operational Art and Aircraft Runway Requirements**

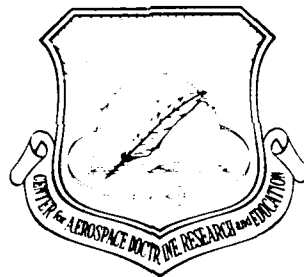
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Report No. AU-ARI-CP-89-4

# Operational Art and Aircraft Runway Requirements

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## ABSTRACT

A commander exercises operational art to achieve strategic goals through his design, organization, and conduct of campaigns. In designing and organizing a campaign, a commander uses movement to provide his forces with the advantages needed to win battles and exploit the opportunities provided by these victories. A key aspect of operational art is the movement of air power so fighter/attack aircraft can fly enough effective sorties when and where they are needed to help win a campaign. The movement of air power depends on the availability and operability of air bases which, in turn, is largely determined by aircraft runway requirements. A review of World War II, Korea, and Southeast Asia shows how important air base availability and operability has been to the effectiveness of fighter/attack aircraft. This same review also shows how increasing aircraft runway requirements have made ensuring air base availability and operability more difficult. Looking to the future, the threat posed by the Soviets promises to make air base availability and operability even more important to success. To make it easier to provide air bases, aircraft runway requirements must be reduced by focusing on the landing phase. Runway required for landing can be reduced by quickly stopping an aircraft *after* it lands or by slowing the aircraft *before* it lands. V/STOL technology offers a particularly effective way of reducing runway requirements because it enables an aircraft to be stopped prior to landing. The value of aircraft using V/STOL technology can best be appreciated if evaluations of aircraft performance apply a campaign rather than a tactical perspective.

## Operational Art and Aircraft Runway Requirements

A COMMANDER exercises operational art to achieve strategic goals through his design, organization, and conduct of campaigns and major operations.<sup>1</sup>

In designing and organizing a campaign, a commander uses movement to provide his forces with the advantages (surprise, concentration, and position) that will give them the best opportunity to win engagements and battles. Likewise, in conducting a campaign, a commander continues to use movement in order to exploit the opportunities provided by the outcome of individual engagements and battles.

While it may not always be fully appreciated, the exercise of operational art is not confined to the movement of ground and naval forces. Operational art also involves the use of air bases to move air power so aircraft—especially fighter/attack aircraft—can fly enough effective sorties when and where they are needed to help win a campaign. By examining the importance of air bases to the exercise of operational art, this article will show why aircraft runway requirements are the key to the availability and operability of air bases during a campaign. It will also show why we must choose between two different approaches for reducing aircraft runway requirements. A choice is necessary if we want to make it easier for a commander fighting a campaign to use air bases to move his fighter/attack aircraft.

The availability and operability of air bases during a campaign is, to a large extent, determined by runway require-

ments for fighter/attack aircraft. When aircraft have very demanding runway requirements (length, width, hardness, and smoothness), it is likely that fewer suitable air bases will be available in a theater. If the number of air bases available is small, their importance to a campaign is likely to grow, making them more lucrative targets and increasing their operability problems.

Of course, availability and operability problems created by aircraft runway requirements are not the only ones afflicting an air base during a campaign. Aircraft maintenance, the supply of fuel and munitions, and command and control can also create serious difficulties. These problems, however, should often be easier to solve. To understand why this is so, we need only compare what is needed to solve the latter problems to the large number of people and immense quantities of equipment, construction material, and transportation resources that are required to build a runway (let alone taxiway and ramp space) for our current fighter/attack aircraft. Unfortunately, an even more important reason is likely to be apparent only during a campaign, when we will be able to see clearly the value of time required to build or repair runways.

When runways require great amounts of resources and time to build or repair, not only are fewer suitable bases likely to be available but also these bases will probably not be located where the sorties they generate can most effectively contribute to a

campaign. This situation is especially true if the campaign involves the rapid movement of surface forces. The location of air bases is extremely important because the distance between a base and the enemy can influence the effectiveness of a fighter/attack aircraft sortie in a variety of ways. If the distance is great, it takes longer to fly a sortie, thereby reducing the number of sorties that a given force structure can fly. Distance also reduces the responsiveness of sorties flown from a particular air base, which can be of critical importance in a fluid battle. Responsiveness can be increased by airborne alert but at a cost of reducing the number of sorties flown.

Airborne alert and/or the need to fly a great distance can also reduce an aircraft's tactical (airborne) performance. Both situations increase an aircraft's fuel requirements, which usually reduce the amount of munitions it carries, its persistence when engaged in combat, and, quite possibly, even the ability to exploit its maximum airspeed (due to the danger of fuel exhaustion). Distance between a base and the enemy is an especially important concern if the threat is such that our aircrews must fly at low altitudes and high airspeeds where fuel consumption is greatest.

Air refueling (depending on the location of the refueling track in relation to the target) is one way we can reduce some of the tactical handicaps caused by the distance between a base and a target. But air refueling increases the complexity of command and control and makes employment more predictable, especially when used frequently. In addition, tanker aircraft require bases with considerable ramp space and long runways. While it is possible to design an aircraft whose tactical performance remains adequate after flying a long distance, the cost of this approach can be high. Such a design may call for larger, heavier, and more complex and expensive aircraft, which

are often vulnerable and difficult to produce and maintain.

If we have only a relatively small number of bases, most of which are located well to the rear, our campaign (particularly its air aspects) is likely to be predictable. Furthermore, fewer available bases often means that more aircraft must be concentrated at each location in order to generate a given number of sorties. If a campaign's success depends on the sorties generated by just a few bases and if each base contains a large number of assets (aircraft, support facilities, runways, taxiways, etc.), these bases will be lucrative targets. It follows that an enemy would be more likely to attack these bases. As an enemy increases his effort to attack our air bases, operability problems will quickly intensify. To appreciate how aircraft runway requirements could affect air base availability and operability in a future campaign, we need to begin by examining past campaigns.

## World War II

THE distances between air bases (or locations suitable for air bases) and the location of enemy forces explain why air base availability and operability were so important in planning, organizing, and conducting our campaigns in the Pacific theater during World War II.<sup>2</sup> Solving the problem of air base availability by either seizing an air base or a location where one could be quickly constructed was usually one of the first objectives in a campaign, as we can see in our decision to invade Guadalcanal.<sup>3</sup> Once we possessed the air base on Guadalcanal, its continued operability—despite Japanese air, land, and naval attacks—proved to be a major factor in our eventual success in that campaign.



Air bases also played an important role in determining which aircraft were most effective. Early in the war in the Pacific, the distances between our bases and the enemy made the long-range P-38 Lightning a very popular aircraft with Gen George C. Kenney, Gen Douglas MacArthur's air commander.<sup>4</sup> Unfortunately, compared to most single-engine aircraft of the time, the P-38 was much larger, more expensive, and more difficult to produce quickly in large numbers.

The relatively limited range of our fighters helped make air bases an important factor in our Northwest African campaign. Gen Henry H. Arnold noted that during the initial landings, "The precious few airfields were not targets for our bombs but immediate objectives on the ground [for our invading ground forces]. Until they were secured, our planes would not be able to operate."<sup>5</sup> Later, after we lost the race of Tunisia, wet weather turned the runways on most of our bases into quagmires. Our nearest all-weather base—at Bône, Algeria—was some 120 miles from the fighting. Moreover, as Maj Gen James H. Doolittle noted, the lack of suitable bases within reasonable range of the enemy meant he could employ at one time only about a third of the 600 aircraft at his disposal.<sup>6</sup> In contrast, the Germans had two all-weather air bases only 20 to 25 miles from the fighting.<sup>7</sup> This basing advantage of the Germans does much to explain our poor performance in the air during this phase of the campaign.

The air base advantages in this campaign were not all on the German side, however. British bases on Malta, despite intense German air attacks, played a key role in the ability of Allied air power to interdict Axis lines of communication across the Mediterranean. The effectiveness of this Malta-based air power in limiting the amount of supplies that reached North Africa contributed significantly to the defeat of the Axis at El Alamein and later in Tunisia.<sup>8</sup>

Our subsequent effort to seize Sicily provides still more evidence of the important role of air bases<sup>9</sup>—a successful campaign. As in North Africa, we chose sites for amphibious landings in Sicily so our forces could capture bases quickly. Before we invaded, however, it was necessary to capture the bases on the islands of Pantelleria and Lampedusa. We needed these bases because single-engine fighters operating out of North Africa did not have the range to provide effective support for our landings in Sicily and because bases on Malta could not support the required number of aircraft. To help make the landings a success, we also used our bombers to make heavy air attacks on German bases in Sicily, Sardinia, and Italy. By reducing German air base operability, these attacks seriously hindered the ability of enemy fighters to interfere with the invasion.<sup>9</sup>

Similar basing considerations continued to dominate our plans for landings in Italy and Northern France. Recognizing that the Germans could be withholding fighters to oppose the invasion of Normandy, we attacked all German air bases within a 150-mile radius of Caen. Our objective was to force the Germans to operate from bases that were as far from Normandy as were our bases in England.<sup>10</sup>

Although we had an extremely large number of fighter-bombers based in England, our commanders knew that the distance to Normandy from English bases would severely limit the effectiveness of these aircraft. Drawing on their experience in previous campaigns, the leadership of the Ninth Air Force made invasion plans based on the idea that "to a tactical air force mobility on the ground is what flexibility is in the air. Fundamental to the mobility of a tactical air force is the provision of airfields where, when, and of types required by the tactical commands and administrative elements most effectively to carry out their respective tasks." To this end they organized, trained, and equipped

Ninth Air Force units to move individually or collectively at a moment's notice.<sup>11</sup>

Putting its plan into action, Ninth Air Force engineers quickly began building bases in France soon after the initial landings. By D day plus five (D + 5) Ninth Air Force had three fighter-bomber airfields under construction on the Omaha beachhead and one on Utah. By D + 16 Ninth Air Force had five fighter-bomber groups (equivalent to today's wings) each with about 72 aircraft based in Normandy. Eight days later, nine all-weather airfields were completed, and seven others were under construction.<sup>12</sup>

By 31 July 1944, 17 fighter groups of the Ninth Air Force were fully operational from bases in France, supporting 19 American divisions. One of these groups was the 405th, whose P-47 "Thunder Monsters" began arriving at strip A-8 on 11 July 1944. The 826th Engineer Aviation Battalion had built the runway at A-8 in only one day using American prefabricated bituminous surfacing (also called Hessian Matting). Besides the runway, A-8 had 75 hardstands for the 405th and 36 hardstands for British Mosquito night fighters that arrived in early August. At first, A-8 was so close to the fighting that the 405th had to make its takeoffs to the east, toward Utah Beach.<sup>13</sup>

The Ninth Air Force continued to emphasize basing mobility as our forces advanced across Europe. For example, to remain near the ground battle during August and September 1944 when Allied armies were making a rapid advance, eight fighter-bomber groups moved to new bases two times; one unit, the 354th, moved three times.<sup>14</sup> Yet, despite its great efforts, Ninth Air Force still had trouble building bases fast enough to keep up with

the Third Army's rapid advance during this period.<sup>15</sup>

## Korea

AIR bases continued to play a critical role in our campaigns during the Korean War. When the rapid advance of invading North Korean forces made bases at Kimp'o and Suwon unavailable, we had no air bases left in Korea whose runways were suitable for the high performance F-80C "Shooting Star." Consequently, we were forced to fly F-80s from bases on Kyushu in Japan, a situation that imposed the same kind of handicaps that had applied to our fighters based in England during the Normandy invasion. Aided by the recall of World War II vintage F-51 Mustangs from storage and by the Air National Guard, however, we were able to field a fighter-bomber that could use the runways that were still available in Korea. Unlike the F-80, the F-51 could operate from short, rough surfaces like the 3,800-foot clay and gravel runway at Taegu. The advantage this ability gave us, despite the F-80's superior airspeed, was apparent when Brig Gen Edward J. Timberlake—deputy commander of Fifth Air Force—noted that "one F-51 adequately supported and fought from Taegu Airfield is equivalent to four F-80s based on Kyushu."<sup>16</sup>

To a large extent, similar basing considerations were the key to the effectiveness of the air support and protection from enemy air attack that our ground forces enjoyed in Korea. Thanks to our frequent air attacks, we usually were able to keep Communist bases in Korea inoperable for all but light aircraft. As a result, Communist fighters were generally confined to areas like "MiG Alley" that were within range of their sanctuary bases in China. By the same token, our ability

to provide effective support to UN ground forces, particularly during their advance out of the Pusan perimeter, depended on how quickly our engineers could make bases in Korea like Kimpo and Suwon operable.

### **Southeast Asia**

WHEN we introduced ground forces into South Vietnam, once again air base availability and operability was the initial objective. As our involvement increased, it soon became evident that there were not enough suitable air bases to support the number and type of aircraft we wanted to employ. Moreover, the location of those bases that were available seriously delayed the responsiveness of many sorties. To make more bases available—especially where they would reduce the time it took a fighter to reach a target—we undertook the construction of additional bases at Cam Ranh Bay, Phan Rang, Phu Cat, and Tuy Hoa.<sup>18</sup>

Examination of the construction of Tuy Hoa is important for what it reveals about trends in our ability to quickly build bases suitable for our fighter/attack aircraft. During World War II, one reason for Ninth Air Force's mobility was that it possessed the resources needed to build or repair bases quickly, even "in the most forward areas under enemy observation and fire."<sup>19</sup> The Ninth also possessed aircraft like the P-47 and P-51 that could use short, rough, easy-to-build runways. In Korea the shortage of engineers and heavy equipment proved to be a "grave deficiency" that had to be overcome before Fifth Air Force could base F-51s—let alone high-performance jets—on the peninsula.<sup>20</sup> By the time we were fighting in Vietnam, our continued emphasis on improving airborne performance (especially airspeed) had resulted in our

fighter/attack aircraft needing runways that were longer, harder, smoother, and cleaner; ramps; taxiways; and more elaborate maintenance facilities. Unfortunately, we had not proportionally increased our engineer capability. To fill the urgent need for air bases, we were forced (and were able) to use civilian contractors to build Tuy Hoa.

The plan we developed allowed the contractor (who was selected on 13 May 1966) to use a 700-man, multi-skilled work force augmented by 600 Vietnamese laborers. After an intensive effort, the contractor finished a 9,000-foot aluminum matting runway on 12 November 1966, *five months* after his advance party had arrived in the theater. In late December—after completing interim facilities including petroleum and ammunition storage, communications, navigation aids, utilities, and roads—the contractor began work on a 9,500-foot concrete runway, finishing on 28 April 1967—*almost a year* after contractor selection.<sup>21</sup> Later, Air Force engineers added aircraft shelters to provide protection from Vietcong mortar and rocket attacks.

Except for these attacks, sometimes involving sappers, the enemy never posed much of a threat to the operability of our bases in Southeast Asia. In contrast, when our self-imposed restrictions were lifted during Linebacker II, our air attacks against North Vietnamese air bases soon ensured that their air force posed little threat.<sup>22</sup>

### **Future Campaigns**

RECOGNIZING the influence that runway requirements for fighter/attack aircraft had on air base availability and operability during past campaigns, we must now determine whether these requirements are likely to have a similar impact in the future. Given the nature of the Soviet threat,

there are powerful reasons why we should believe that the runway requirements of our aircraft will be an even more important factor in future campaigns than they were in the past.

We find one reason for this belief in one element of an offensive that Soviets call the air operation.<sup>25</sup> The Soviets recognize that a successful offensive depends on air superiority. After studying our strengths (particularly the caliber of our aircrews and the nature of our aircraft technology) and the extent of our weaknesses, the Soviets have apparently decided that the best way to gain air superiority would be to fight our Air Force when it is *on the ground* rather than in the air.<sup>25</sup> They seem to believe that this plan is most feasible if they use a combined arms approach to overwhelm our defenses.

More than likely, a Soviet air operation would simultaneously employ a variety of methods (involving missiles, aircraft, and special-purpose troops) and munitions (instant, delayed, unitary, and bomblet), making a surprise attack on our air bases and other essential facilities in mass and in depth. Success, in Soviet eyes, would depend on whether our aircraft could fly the large number of effective sorties at the right place and time that are likely to be needed to gain and maintain the necessary degree of air superiority, *let alone* perform effective ground attack. Even if a relatively large portion of our aircraft survived on the ground but could not get airborne at the times and in the numbers needed to win key engagements and battles, their air operation would be a success. This would be due to the fact that our potentially superior airborne tactical performance would not materialize and would thus be irrelevant to the outcome of the campaign.

Yet the air operation is not the only reason our aircraft runway requirements may be vital to the outcome of future campaigns. The Soviet offen-

sive is also designed to achieve high-tempo, mobile, ground operations that will penetrate our rear area quickly and deeply. If Soviet forces are able to carry out this operation, they would soon put many of our air bases at risk, as was the case during North Korea's 1950 invasion of South Korea.

Besides using a rapid advance to threaten our air bases, the Soviets are prepared to repair captured air bases quickly and, if necessary, build new ones. Their purpose would be to reduce the distance between their bases and the leading ground elements of the offensive. They consider their ability to operate from frontline runways to be a major advantage. In contrast, they believe our aircraft are "too heavy and sluggish" to be based near the front—a factor that causes our reaction time to be too slow to "meet the norms."<sup>26</sup>

Further indications of the importance that the Soviets assign to securing advanced bases are evident in exercises like *Zapad 81* and their incursions into Czechoslovakia and Afghanistan.<sup>26</sup> (One expert has written that to help secure advanced bases, the Soviets normally include an airfield engineer battalion in a tank army's order of march.<sup>27</sup>) In case of a war in Europe, the Soviets have already ensured that they will have plenty of air bases nearby. In East Germany alone, they have built at least 27 large and 13 medium sized airfields, most with aircraft shelters. Besides these airfields, they have also prepared standby forward air bases and equipped highways to serve as runways.<sup>28</sup>

Unlike our approach to fighter/attack aircraft design, the Soviets ensure that most of their aircraft assigned to theaters of military operations (IVDs) are capable of using temporary gravel runways. For example, the MiG 29 Fulcrum has large, low pressure tires, a nose gear set aft to keep from spraying gravel into the intake, and an auxiliary inlet system to reduce the

probability of foreign object damage.<sup>29</sup> Looking to the year 2000, the commander of the Soviet air force (VVS), Marshal of Aviation Aleksandr Yefimov, also emphasized that operations of the VVS should not be affected by runway damage. He stated that "much attention is being given to developing short take-off and vertical landing aircraft capable of operating from damaged airstrips."<sup>30</sup> The ability of Soviet aircraft to use gravel runways means Soviet engineers should be able to quickly build runways close to the ground battle and rapidly repair any damage to these runways. This capability could be especially important if we were involved in a war with the Soviets in Southwest Asia where there are relatively few suitable air bases.<sup>31</sup>

### **Reducing Runway Requirements**

TO help counter this growing Soviet threat, we must improve our air base availability and operability. If the past is any guide, an effective way of doing this would be to reduce the runway requirements of our fighter/attack aircraft. Should we take this approach, we must devote most of our attention to reducing landing-distance requirements. This emphasis is necessary because technological advances—especially higher-thrust engines—that have significantly reduced takeoff rolls have not had much effect on reducing the runway specifications (length, width, strength, and smoothness) needed by our fighter/attack aircraft to recover at a base.

Differences between a fighter's acceleration during takeoff and its deceleration when landing help explain why runway availability is more critical for landings than takeoffs. Due to their high thrust-to-weight engines,

modern fighters can accelerate on takeoff much more quickly than they can decelerate when landing.<sup>32</sup>

Aircraft velocity is another reason that runway requirements for landing are more demanding than those for takeoff. A pilot begins a takeoff at zero velocity, yet if he is landing an aircraft like the F-15 Eagle, he approaches the runway at approximately 135 knots.<sup>33</sup> This difference in velocity leads to a number of problems, especially if a pilot is attempting to land in darkness, during periods of poor visibility, or on a damaged runway. First, high approach speeds during landing make it far more difficult for a pilot to find the runway. High speed also makes it vital for a pilot to learn the runway's condition (damaged, wet, or icy) before landing.<sup>34</sup> Knowing the exact location of runway damage is important because a pilot must determine where it is safe to touch down. Even this information may not be enough because the references a pilot normally uses when landing are likely to make it very difficult to "overfly" a damaged portion of the runway, especially at night or in poor visibility.

High speed, especially when combined with the effect of winds, makes it more difficult for a pilot to line up with the runway for landing than for takeoff. High speed also makes it more difficult for a pilot to touch down as close as possible to the beginning of the usable runway, let alone do this at the ideal airspeed.<sup>35</sup> (In contrast, it is easy to make sure a takeoff begins precisely at the end of the usable runway.) The relationship between airspeed and difficulties in landing becomes even more apparent when we realize that the occurrence of accidents for land-based aircraft increases by the square of the approach speed.<sup>36</sup> During a future war—especially one with the Soviets—aircraft losses resulting from accidents during high-speed landings have the potential of becoming a much more serious factor than they have been in

the past.<sup>37</sup> The use of systems such as low-altitude navigation and targeting infrared system for night (LANTIRN) adds to the problem because it increases the probability that we will be attempting more landings in darkness and marginal weather. Finally, the small size of our force structure and our limited-production capacity make us less able to tolerate losses from landing accidents than we could in past wars.

Compounding these problems is the possibility that many accidents in a future war will be due to fuel exhaustion or to fatigue. That is, pilots already fatigued by the stress of combat are more likely to be attempting to land under marginal conditions to avoid fuel exhaustion. In peace, we can avoid these dangers by ensuring that pilots are well rested, allowing landings only in favorable weather conditions at suitable fields, and by requiring a conservative fuel reserve. Unfortunately, these measures are unlikely to be satisfactory in war because they would seriously interfere with our ability to fly large numbers of effective sorties in marginal conditions when air power may be needed most.

### **Reducing Runway Requirements for Landing**

**W**E should be able to decrease the dangers associated with landing and, more important, increase air base availability and operability by reducing the runway landing requirements of our fighter/attack aircraft. However, to reduce these requirements we must choose between two different methods. One method involves quickly stopping the aircraft *after it touches down*. The other focuses on reducing an aircraft's speed *before it lands*.

Attempting to quickly stop an aircraft after it lands presents a number of problems. It does little to reduce

the difficulties involved in finding a runway, learning its condition, accurately lining up the approach, or ensuring that an aircraft lands as slowly as possible at a desired point on the runway. Attempting to solve the last problem by making inflated "carrier" landings imposes a significant weight penalty, requires stronger, smoother runway surfaces, and prevents using the flare to reduce touchdown speed.<sup>38</sup> Improvements in fighter/attack aircraft wheel brakes have so far been insufficient to shorten stopping distance significantly. Moreover, brakes are even less effective when weather reduces a runway's coefficient of friction. High-drag devices like drag chutes can help; however, they are dangerous to use in high crosswinds and are less effective when an aircraft—like the F-15—lands at a relatively modest airspeed.<sup>39</sup>

Arresting gear is another way to stop a landing aircraft in a short distance, but there is an obvious risk if the gear is not functional or if an aircraft fails to engage and is unable to take off and try again. Even if the engagement is successful, it can take at least two minutes to reset the gear, making the runway unavailable—if only briefly—for more takeoffs or landings. If several aircraft attempting to land are in danger of running out of fuel or if aircraft must be scrambled immediately, this delay could cause serious problems.<sup>40</sup>

Thrust reversers provide still another way of reducing runway landing requirements. Unfortunately, these devices are expensive, add as much as 850 pounds to aircraft weight, and introduce maintenance problems. They can also lead to an engine's ingesting loose ground material (likely to be present on a damaged runway) and may degrade an aircraft's directional stability during a landing roll.<sup>41</sup>

The other method is to reduce an aircraft's speed before it touches down. One way to do this is by increasing the lift of the wings in order to reduce the

aircraft's stall speed. Lift can be increased by varying the sweep of an aircraft's wings or by increasing the camber of its wings through the use of leading-edge devices and flaps. Unfortunately, both of these procedures are complex and add to an aircraft's weight and cost. Worse, because these procedures depend on wind-over-the-wing to provide lift, their ability to reduce landing speed is limited—principally because lift varies as the square of airspeed. For example, even the highly modified short takeoff and landing (STOL) and STOL maneuvering technology demonstrator (SMTD) F-15 is expected to have a final-approach speed of approximately 119 knots—only 16 knots slower than an unmodified F-15.<sup>42</sup>

Another way to reduce speed is by using jet thrust rather than aerodynamics to provide lift. The AV-8B Harrier II demonstrates the advantage of this method because its design allows a pilot to use vectored thrust to stop and sustain the aircraft *while it is still in the air*. Consequently, a pilot flying an AV-8B can land the aircraft vertically with an approach speed of zero knots forward velocity.<sup>43</sup>

A vertical landing capability produces a number of important advantages. In order to land, for example, a pilot needs a surface only a little larger than the aircraft. Moreover, this surface can be fairly soft and rough, and it does not matter whether it is wet or icy.<sup>44</sup> By making a wide variety of surfaces (such as taxiways, roads, and even parking lots) suitable for landings, vectored thrust greatly reduces the probability that a pilot will need to divert because a runway is unavailable. In war, this capability could mean that far fewer aircraft would be lost due to either fuel exhaustion or landing accidents. Perhaps just as important, landing vertically has the potential to reduce or even eliminate most of the safety problems caused by high velocity during approach and touchdown.<sup>45</sup>

The advantages of vectored thrust are not confined to landings. If a runway is used only for takeoffs, sortie-generation rates and responsiveness are improved because takeoffs are not subject to delays caused by aircraft recoveries. Using a runway only for takeoffs also has the advantage of eliminating any danger of a landing aircraft colliding with one taking off—a possibility that becomes more likely when communications and visibility are poor. Used on takeoff, vectored thrust can shorten takeoff rolls to between 500 and 1,500 feet (depending on gross weight); even a vertical mode of launch is possible.<sup>46</sup> (Although vertical takeoff limits the amount of fuel and munitions an aircraft carries, this capability would be particularly useful in two situations: (1) "flushing" to avoid being caught on the ground by an attack and (2) repositioning aircraft that landed away from the base, perhaps because the base was under attack or because they were low on fuel.) Vectored-thrust aircraft should also have better range/payload characteristics than comparably sized conventional aircraft because the weight handicap caused by a large fuel reserve could be eliminated.<sup>47</sup> When used in combat maneuvering, vectored thrust can improve an aircraft's agility and deceleration capability, further improving its mission performance.<sup>48</sup>

Despite these advantages, fighter/attack aircraft capable of using vectored thrust to make vertical landings currently have a number of limitations. Designs generally are for relatively small aircraft like the AV-8B, which is comparable in size to the F-16. Considerations of weight and center of gravity are very important and can constrain aircraft design. Another problem of design involves providing enough air to the engine at low airspeeds and in hover. For this reason, the AV-8B has large intakes that create a large signature and produce drag, which limits its maximum airspeed. Due to the increased

thrust requirements, vertical-landing, vectored-thrust aircraft will be incapable of supersonic airspeeds until a satisfactory plenum-chamber-burning engine is available. For attack aircraft, however, the lack of supersonic airspeed is not a serious deficiency because they cannot afford the fuel consumption demanded by supersonic speed—especially when carrying air-to-surface munitions and operating at low altitudes.

### Conclusions

CLEARLY, we must reduce the runway requirements of our fighter/attack aircraft so we can enhance a commander's ability to exercise operational art by using air bases to move his air power. To determine which approach is best for reducing a particular aircraft's runway requirements, we must use a campaign perspective when assessing the potential combat contribution or value of that aircraft. A campaign perspective is necessary because this is the *only* way we can see the truly immense influence that air bases (and runways) have on a fighter/attack aircraft's actual combat capability. Consequently, we must reexamine the tools (such as simulations and exercises) we use to evaluate a current or proposed fighter/attack aircraft's performance to see how well these tools apply a campaign perspective, if at all. For example, applying a

campaign perspective means that a simulation's validity as an assessment tool depends on whether it can show how air base availability and operability influence an aircraft's tactical (airborne) performance. Similarly, if an exercise is to be valid, air base availability and operability can no longer be taken for granted. To be reliable assessment tools, both simulations and exercises must pay special attention to the availability of engineers, construction equipment, transportation, and building materials in a theater. These factors will affect our ability to quickly build or repair the number and type of runways required by a specific type of aircraft. Nor can these simulations and exercises be considered valid if they ignore how the distance between a base and the enemy affects the contribution to a campaign made by aircraft at that base (number of sorties flown, responsiveness, amount of munitions delivered, persistence in combat, and ability to exploit the maximum airspeed). Both tools must also have the sensitivity to assess the effect of this distance on the possibility of aircraft being lost due to landing accidents or fuel exhaustion. Finally, simulations and exercises must be able to evaluate how simultaneous runway closings at several bases—even if only for a few hours—affect the remaining bases in the theater, especially their ability to generate and recover sorties and their vulnerability to enemy attack.



## Notes

1. Army Field Manual 100-5, *Operations*, 5 May 1986, 10. For further discussion of relational maneuvers and operational art, see Edward N. Luttwak, *Strategy: The Logic of War and Peace* (Cambridge, Mass.: Harvard University Press, 1987), 91-112.
2. Gen George C. Kenney, *Reports of the Pacific War* (New York: Duell, Sloan and Pearce, 1949), 216, 394, 416, 478.
3. Wesley F. Craven and James L. Cate, eds., *The Army Air Forces in World War II*, vol. 4, *The Pacific: Guadalcanal to Saipan, August 1942 to July 1944* (Chicago: University of Chicago Press, 1949), 26-29.
4. Gen Henry H. Arnold, *Global Mission* (New York: Harper & Brothers, Publishers, 1949), 337-38; Kenney, 377.
5. Arnold, 326.
6. Craven and Cate, vol. 2, *Europe: Torch to Pointblank, August 1942 to December 1943* (Chicago: University of Chicago Press, 1949), 116; see also 83, 89-91, 94, 100, 117-21.
7. Charles Messenger, *The Tunisian Campaign* (London: Ian Allan Ltd., 1982), 12-14; and Jack Coggins, *The Campaign for North Africa* (Garden City, N.Y.: Doubleday and Co., Inc., 1980), 102-4.
8. For a short but thorough account of how the interdiction of German lines of communication in the Mediterranean contributed to Allied victory, see Martin Van Creveld, *Supplying War: Logistics from Wallenstein to Patton* (New York: Cambridge University Press, 1977), 181-201.
9. Craven and Cate, vol. 2, 415-25.
10. Craven and Cate, vol. 3, *Europe: Argument to V-E Day, January 1944 to May 1945* (Chicago: University of Chicago Press, 1951), 69.
11. Col William B. Reed et al., eds., *Condensed Analysis of the Ninth Air Force in the European Theater of Operations* (Washington, D.C.: Headquarters Army Air Forces, 1946; new imprint, Office of Air Force History, 1984), 3.
12. *Ibid.*, 20-25.
13. Reginald G. Nolte, *Thunder Monsters over Europe* (Manhattan, Kans.: Sunflower University Press, 1986), 27.
14. Dr Alan F. Wilt, "Coming of Age: XIX TAC's Roles During the 1944 Dash Across France," *Air University Review*, March-April 1985, 84.
15. The increasing distance between XIX Tactical Air Command's (TAC's) bases and advancing ground units created a problem with loiter time for fighter-bombers flying armored column cover. In order to maintain this cover until new bases could be built, the Ninth Air Force temporarily had to increase XIX TAC's force structure by giving it operational control over some IX TAC units. Reed, 30. See also Nolte, 40-48, for a detailed description of how the 405th's operations were adversely affected by the increasing distance between its base and the enemy.
16. Robert Frank Futrell, *The United States Air Force in Korea 1950-1953* (Washington, D.C.: Office of Air Force History, 1983), 65-68, 87, 94-95.
17. *Ibid.*, 176-84, 694-95.
18. Maj Jeffrey L. Tyley, "Project Turnkey: Historical Perspectives and Future Applications," *Air Force Journal of Logistics*, Summer 1987, 4-5.
19. Reed, 3, 8, 19-11, 108-9.
20. Futrell, 176.
21. Tyley, 4-9. The Air Force still has relatively little ability to build air bases. There are only seven (four in the active force) 400-man, mobile, self-sufficient, heavy engineering units organized, trained, and equipped to build or upgrade air bases. Robert Paterson and Dana Lombardy, "Forward Airbases," *NATO's Sixteen Nations*, April 1987, 86.
22. Gen William W. Momyer, *Air Power in Three Wars* (Washington, D.C.: Government Printing Office, 1978), 141-50, 215-16, 236-42.
23. For a perspective on the nature of this threat, see Phillip A. Peterson and Maj John R. Clark, "Soviet Air and Antiair Operations," *Air University Review*, March-April 1985, 36-54.
24. Col V. Kirillov, "Conventional Wars and Ways of Waging Them," *Krasnaya zvezda*, 4 October 1986, 5. Published in "Soviet Press Selected Translations," *Current News*, no. 1599 (30 June 1987): 90.
25. Col V. Kirillov, "The Fighter-Bomber in Combat," *Aviatsiya i kosmonavtika*, no. 7 (1986), 29-35. Published in *Current News*, no. 1650 (29 October 1987): 145-47.
26. Maj Roger E. Bort, "Air Assault Brigades: New Element in the Soviet Desant Force Structure," *Military Review*, October 1983, 31-38.
27. Richard Simpkin, *Red Armour* (New York: Brassey's Defence Publishers, 1984), 161.
28. Gunter Lippert, "GSFG Spearhead of the Red Army," *International Defense Review*, May 1987, 561.
29. Bill Sweetman, "The New Soviet Fighters—How Good Are They?" *Interavia*, June 1987, 578-79.
30. *Jane's Defence Weekly*, 13 February 1988, 279.
31. Michael McGwire, "Update: Soviet Military Objectives," *World Policy Journal*, Fall

1987, 723-31. He speculates that the Soviets may not believe a "major conflict with the United States in the Persian Gulf region would necessarily escalate to world war." This development could explain the addition of three TVDs, including one for the Indo-Arabian region.

32. Most modern fighters can accelerate on takeoff at about one gravity (g) (20 knots/second/second), yet—despite a lower weight and airspeed when landing—can usually decelerate at only about .25g (fighters cannot decelerate at .5g even when using thrust reversers). Dr John W. Fozard, "Tactical Jet V/STOL—Its Future in a CTOL World," SAE Technical Paper Series, no. 861637 (Long Beach, Calif.: Aerospace Technology Conference and Exposition, 13-16 October 1986), 51; also author's correspondence with Dr Fozard.

33. Jeffery P. Rhodes, "Landing on Less," *Air Force Magazine*, April 1987, 74-76.

34. Stopping on a wet runway takes 1.3 times the distance needed if it is dry. Icy runways increase the stopping distance to 3.2 times the dry distance. Ray Whitford, *Design for Air Combat* (London: Jane's Publishing Co., Ltd., 1987), 208.

35. Current aircraft have a touchdown longitudinal dispersal of plus or minus 500 feet. Robert R. Ropelewski, "Modified F-15 Will Investigate Advanced Control Concepts," *Aviation Week & Space Technology*, 11 February 1985, 51-53; and Bill Sweetman, "Short-field F-15," *Interavia*, July 1986, 791-92.

36. Whitford, 67.

37. One reason for this possibility is that—unlike most of our past experience—we would probably be operating from air bases that have been under attack. If our bases are attacked, it is likely that runways, arresting gear, navigation aids, and other equipment or facilities necessary for safe landings will be damaged or destroyed. At the same time, compared to the aircraft we had in World War II and the Korean War, our current aircraft are far more dependent on long, hard, smooth, clean runways to make a safe landing. This requirement means that relatively few suitable runways are likely to be available.

38. Modifying even the small T-45 Hawk to make it capable of carrier operation (catapult launch and unflared, arrested landing), increased its weight by 960 pounds, mostly due to the landing requirements. This amounts to over 10 percent of its operating weight when empty. Dr John W. Fozard, "Harrier—Catalyst for Change in Naval Airpower," *Aerospace* 12, no. 5 (May 1984): 5-26.

39. Whitford, 207.

40. "USAF Tests Arresting Systems," *Aviation Week & Space Technology*, 2 January 1984, 45.

41. Testing of the British Tornado aircraft showed there could be aerodynamic interference between reverser efflux and aircraft control surfaces that could degrade the aircraft's lateral stability. Consequently, the aircraft would have difficulty staying on the runway. Whitford, 208-9.

42. Rhodes, 74-76. Of course, this reduction in speed will make wheel brakes more effective when the runway is dry.

43. Slowing a Harrier to a hover from 200 knots wingborne flight speed takes less than 30 seconds, only 3,000 feet of airspace, and less than 100 pounds of fuel. Repositioning in a hover over a distance of 1,500 feet in half a minute uses less than an additional 100 pounds of fuel. John W. Fozard, *Ski-Jump, A Great Leap for Tactical Airpower*, AIAA, First Atlantic Aeronautical Conference, March 1979, 5.

44. The AV-8B can safely use a landing surface with a California bearing ratio (CBR) of six, while an F-16 needs a surface with a CBR of almost fourteen. A baseball outfield has a CBR of nine, and a wet putting green is four. AV-8B *Rapid Deployment Overview* (St. Louis, Mo.: McDonnell Douglas Corporation, 1980), 24-25.

45. A number of changes have been made in the AV-8B: a new two-seat trainer, excellent cockpit visibility, a more effective reaction control system, engine improvements, and most important—a stability augmentation and attitude-hold system that is operational throughout the hover envelope. Consequently, the pilot skills necessary to hover and land vertically have been greatly reduced compared to those required for the AV-8A. Brendan M. Greeley, Jr., "Improved VTOL Performance of TAV-8B Adds Realism to Attack Force Training," *Aviation Week & Space Technology*, 3 August 1987, 68-76.

46. An AV-8B can take off in less than 1,500 feet on a tropical day, carrying fuel and ordnance equal to 130 percent of its empty weight. In addition, only an aircraft with a vectored-thrust capability can make full use of a ski-jump launch that reduces takeoff rolls by up to 50 percent. Finally, contrary to popular misconceptions, a vertical takeoff requires little fuel—less than 100 pounds to reach weight-on-wings airspeed. Fozard, *Ski-Jump*, 11-13; "Tactical Jet V/STOL," 34; AV-8B *Harrier II: A Closer Look* (St. Louis, Mo.: McDonnell Douglas Corporation, n.d.), 2.

47. According to one Sea Harrier pilot who flew more than 60 day and night combat sorties during the Falklands War, he never got back to his ship with more than 500 pounds of fuel. Once, after shooting down a C-130, he had only 150 pounds of fuel when he landed. Alfred Price, *Harrier at War* (London: Ian Allan Ltd., 1984), 63.

48. Fozard, "Tactical Jet V/STOL," 47-48.

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